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Category (CAT) IIIb Level 1 Test Plan for Global Positioning System (GPS)

September 1993

Final Report

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16. Abstract

The FAA has established a program to demonstrate the feasibility of differential GPS (DGPS) based technology for Category (CAT) IIIb precision approach and landing applications. DGPS includes code corrections and phase differencing or phase correction (real-time kinematic) techniques. Contractors will provide complete systems including ground reference and signal monitor equipment, ground-air data link, and an aircraft instrumented with DGPS receiver/processor driving a flight director/autopilot. Several contractor systems are expected to undergo flight testing and optional satellite simulator testing. This Level 1 plan describes the test concepts and objectives, and also outlines the preparation of Level 2 and Level 3 Test Plans.

The primary objective of the flight test is to demonstrate whether a contractor's DGPS system meets either sensor accuracy requirements for CAT IIIb approaches or the total system error requirements of the new tunnel-in-space concept. Additional objectives are to demonstrate adequate integrity and continuity of service. This plan describes specific objectives, guidelines and measures of success (MOSs) for the flight tests. The primary objective of the optional satellite simulator testing is to determine the robustness and integrity characteristics of a contractor's system in response to variations in satellite signals that cannot readily be produced during flight testing. This plan describes specific characteristics to be measured by the satellite simulator testing.

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CAT IIIb Level 1 Test Plan for GPS

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Research & Development Service
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The FAA has established a program to demonstrate the feasibility of differential GPS (DGPS) based technology for Category (CAT) IIIb precision approach and landing applications. DGPS includes code corrections and phase differencing or phase correction (real-time kinematic) techniques. Contractors will provide complete systems including ground reference and signal monitor equipment, ground-air data link, and an aircraft instrumented with DGPS receiver/processor driving a flight director/autopilot. Several contractor systems are expected to undergo flight testing and optional satellite simulator testing. This Level 1 plan describes the test concepts and objectives, and also outlines the preparation of Level 2 and Level 3 Test Plans.

Steve Zaidman

ABSTRACT

The FAA has established a program to evaluate the technical feasibility of using the satellite-based Global Positioning System (GPS) for Category IIIb precision approaches. This Level 1 Test Plan provides an overview of concepts, objectives and requirements for flight tests and satellite signal simulator tests (optional) to be used in the evaluation. Emphasis will be placed on meeting CAT IIIb accuracy and integrity requirements (as set forth in this plan). It is expected that differential GPS (DGPS) techniques such as code corrections or phase (real-time kinematic) corrections will be needed to meet the accuracy requirements. Contractors will be requested to supply the ground equipment for computing, transmitting and monitoring the corrections as well as a completely instrumented aircraft for the feasibility demonstration. The minimum airborne equipment shall include a GPS receiver/processor (sensor) with output coupled to a flight director. It is highly desirable that the DGPS sensor also be coupled to an autopilot for demonstrating complete CAT IIIb autoland capability. Guidance may be derived from the GPS sensor alone or integrated with inertial reference system (IRS) and barometric or radio altimeters. Flight test evaluation will be based on completing 100 approaches, 90 touch and go, 10 with roll out to complete stop. Two types of accuracy requirements will be evaluated: 1) sensor accuracy based on International Civil Aviation Organization (ICAO) requirements for the Microwave Landing System (MLS), or 2) total system error (difference between desired and actual aircraft path) based on the newly devised tunnel-in-space concept. More detailed requirements and measures of success for accuracy and integrity performance during the flight tests are also included in the plan. Satellite simulator tests (if used) will characterize the performance of contractor systems under conditions not readily achieved during flight testing. The plan also describes concepts for a flight readiness review to assess contractor system fundamental performance prior to any flight (or simulator) testing. Additional test details will be set forth in separate Level 2 Plans for Flight Tests and Simulator Tests, and in Level 3 Plans coordinated between the testing organizations and individual contractors.

PREFACE

This Level 1 Test Plan was written to provide an overview of the test concepts, objectives and requirements for evaluating the technical feasibility of using differential Global Positioning System (DGPS) guidance for Category IIIb (CAT IIIb) precision approach and landing applications. The information presented herein will be used by those who propose to build DGPS systems for evaluation, by those who will write Level 2 and Level 3 Test Plans, and by those who will conduct the flight and simulation tests comprising the feasibility demonstration.

ACKNOWLEDGEMENTS

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INTRODUCTION

1.1 BACKGROUND

The FAA has established a program to demonstrate the feasibility of differential GPS (DGPS) based technology for Category (CAT) IIIb approach applications. CAT IIIb is defined in Advisory Circular (AC) 120-28C [1] as "a precision instrument approach and landing with no decision height (DH), or with a DH below 50 feet (15 meters), and controlling runway visual range (RVR) less than 700 feet (200 meters), but not less than 150 feet (50 meters)". Further program details are contained in the Statement of Work. DGPS is defined to include, but not limited to, code corrections and/or phase differencing or phase correction (real-time kinematic) techniques. Systems from several contractors are expected to undergo flight readiness review, flight testing, and optional satellite simulator testing. Analyses to demonstrate feasibility (e.g., signal availability to satisfy contractor's satellites-in-view constraints) will complement the testing effort.

The purpose of this plan is to provide the test objectives, concepts, and an outline of the test plan and preparation process.

1.2 OVERVIEW OF TEST CONCEPTS

Table 1 contains a summary of the concepts of the three types of tests. Appendix A summarizes contractor responsibilities for determining level of effort for the test phases.

Table 1. Summary of Test Concepts

TEST	CONCEPT
Flight	Verify that a contractor's equipment meets CAT IIIb requirements (as specified in this plan) for either sensor accuracy or total system error and integrity (including touchdown and rollout).
Satellite Simulator	Determine the characteristics of the integrity function, robustness, and accuracy of a contractor's equipment by testing performance during events that are not easily encountered during flight testing.
Flight Readiness Review	Verify the readiness of contractor's equipment for flight tests.

1.2.1 Flight Test

The primary objectives of the flight test are to demonstrate whether a contractor's GPS/DGPS system provides sufficient capability to meet CAT IIIb requirements (as specified in this plan) for either sensor accuracy or total system error and integrity.

The equipment to be flight tested will be capable of providing CAT IIIb accuracy and fitted in a contractor provided aircraft. The 100 completed approaches required for the flight tests will be carried out at government test facilities under meteorological conditions appropriate to test safety and instrumentation needs. The contractor will provide the ground reference and signal monitor station equipment, the data link, and the airborne receiver/processor. The contractor is solely responsible for ensuring that the interfaces provide the proper data flow for the equipment to meet its performance, and for collecting the required sensor data in a format designated by the FAA. The sensor data collection time stamp will be synchronized (within one millisecond) with that of the ground truth reference (laser tracker and TV).

1.2.2 Satellite Simulator Test

Based on the results of flight testing, at the FAA's option, a contractor system may be subjected to a satellite simulator test (SST). The primary objective of the SST is to determine the robustness and integrity characteristics of a contractor's equipment during variations in the simulated satellite signals. The simulations will be based on events that cannot readily be duplicated during flight testing. A secondary objective is to verify the accuracy of the contractor's equipment.

The equipment to be tested will be each contractor's avionics (up to the guidance signals) used in conjunction with its ground-reference and signal monitoring equipment. The test signals and flight paths will be generated by a GPS simulator located at a government facility. An interface control document (ICD) defining the interfaces to government test equipment will be provided for this test. The contractor will comply with the interface requirements of the test facility. In the case of an integrated navigation system (e.g., including inertial reference system (IRS) and altimeters), the contractor will provide the interface and performance characteristics of the inertial system and its integration. The inertial unit and/or altimeters will be simulated by approved software, and the contractor will provide the complete DGPS system.

1.2.3 Flight Readiness Review

The general objective of the flight readiness review is to provide a limited demonstration of the real-time capability of a contractor's equipment to determine whether it is ready for flight testing.

The flight readiness review shall consist of five successful approaches of the contractor's aircraft where the approach guidance is provided by the contractor's DGPS-based system. These approaches will be at a government test facility, and will be observed by FAA representatives who will make the decision as to whether the equipment is ready to undergo flight tests.

1.3 PARTICIPATING GOVERNMENT ORGANIZATIONS

The following government organizations will provide the test support and facilities.

FAA Technical Center: The Technical Center is one of the primary organizations and facilities for flight testing the contractor's equipment. The basis for the flight tests will be a standard straight-in instrument approach replicated 100 times. The Technical Center flight tests shall be conducted at Atlantic City International Airport.

NASA Ames Research Center: Ames is one of the primary organizations and facilities for flight testing the contractor's equipment. The basis for the flight tests will be a standard straight-in instrument approach replicated 100 times. The NASA Ames Research Center flight tests shall be conducted at Crows Landing.

Naval Research and Development (NRaD) Test and Engineering Division Detachment: NRaD will be the organization and facility to provide the satellite simulator tests. The basis of the simulation will be a GPS satellite signal generator, a scenario generator to simulate different flight paths, and IRS and altimeter sensor simulators if used in the contractor's navigation solution. If a contractor's system is subjected to the optional simulator tests, the complete system (receivers, ground reference and monitor equipment) will be tested.

1.4 TEST PLAN PROCESS

The test plan process is divided into three "levels." The Level 1 Test Plan (this document) provides a high-level description of test concepts, objectives, and guidelines. The Level 2 Test Plan defines requirements and details of the testing based on the Level 1 Test Plan, and the Level 3 Test Plan defines the actual procedures for each DGPS system that will be tested to satisfy the requirements defined in the Level 2 Test Plan. The following descriptions provide more detail on each of the levels:

Level 1. In the Level 1 Test Plan (this document), the test concepts, objectives, measures of success, data to be collected, definition, and organization are defined. The preparation of the Level 1 Test Plan is the responsibility of MITRE's Center for Advanced Aviation System Development (CAASD). This process is coordinated by the Satellite Program Office (ARD-70) and done in conjunction with the Satellite Operational Implementation Team (SOIT) and Stanford University. The result is a Level 1 Test Plan that has been approved by the SOIT and the Program Office. This test plan will be provided in the Request for Proposals (RFP) so that contractors may be specifically aware of the test phase's measures of success (defined below) and level of effort required for the testing (see Appendix A).

Level 2. The Level 2 Test Plan will define the comprehensive test requirements for each measure of success evaluation. The Level 1 Test Plan will be used as a guide to develop the Level 2 Test Plan. The test requirements will detail the data analysis procedures, format of data to be collected, approach trajectories, environmental scenarios, number of approaches, and truth sources to be employed. The Level 2 Test Plan will include the standard outline for Level 3 plans. The Level 2 process

will be the responsibility of MITRE's CAASD for the flight tests and NRaD for the satellite simulator tests. There is no Level 2 Test Plan for the flight readiness review. In developing the Level 2 Test Plans, guidance from the participating government test organizations, the Program Office, FAA CAT III certification and flight test experts, the SOIT and Stanford University will be obtained. The result is a Level 2 Test Plan that has been approved by the Program Office, SOIT and Stanford University.

Level 3. The Level 3 Test Plan will define the procedures and test scripts that will address how the requirements in the Level 2 Test Plan will be met. Level 3 planning is to be carried out by each participating test organization in coordination with each contractor. They will use the Level 2 Test Plan as the requirements for the testing. There will be a Level 3 Test Plan for each contractor's DGPS system to be tested. The outline for the Level 3 Test Plan will be contained in the Level 2 Test Plan.

1.5 OUTLINE OF DOCUMENT

The remainder of this document is divided into three parts. Section 2 contains the Level 1 flight test plan, Section 3 contains the Level 1 satellite simulator test plan, and Section 4 contains the Level 1 flight readiness review plan.

SECTION 2

FLIGHT TESTS

2.1 TEST OBJECTIVES

The overall objective is to verify that a contractor's system demonstrates capability to meet requirements (as specified in this plan) for accuracy and integrity over 100 completed CAT IIIb approaches. A maximum of 110 trials will be allowed to complete 100 approaches. Specific objectives are:

1. Accuracy (95%): Determine whether the equipment meets (refer to Figure 1) (1) International Civil Aviation Organization (ICAO) Annex 10 [2] MLS requirements for sensor accuracy, or (2) FAA AC 20-57A (Automatic Landing Systems) [3], AC 120-28C (Criteria for Approval of CAT III Landing Weather Minima) [1] and the FAA tunnel-in-space [4] requirements for total system error for a straight-in ILS like approach for CAT IIIb. For both (1) and (2) additional sensor information may be blended for determining guidance as restricted by test guideline 4 below.

2. Integrity Monitor Response: During the final approach segment, determine whether the system equipment integrity monitoring response has a low alarm rate and detects out of tolerance sensor errors. Although no satellite signal anomalies will be intentionally introduced, the equipment is expected to detect all anomalies which do occur. Further, the equipment will not be expected to generate any false alarms. A second set of more stringent limits will be used to check integrity logic and response time with the aircraft stationary on the ramp.

2.2 TEST GUIDELINES

1. The Level 3 Test Plans must be based on the Level 2 Test Plan, and approved by the FAA as capable of meeting the verification of the flight test measures of success. A Level 3 Test Plan will be developed for each contractor.

2. Each test organization will provide the contractor with the test approach plate, waypoints, and runway threshold coordinates as part of the Level 3 Test Plan.

3. Each contractor will provide the FAA with the GPS constellation geometry constraints required for its equipment to meet the measures of success (MOSs) for accuracy requirements (e.g., dilutions of precision (DOPs), mask angle, minimum number of satellites). These will be provided at least (30) days prior to the flight readiness review. Using its GPS availability model with the 24 satellite constellation in place at time of flight tests, the FAA will determine the availability of the DGPS service that satisfies the geometry constraints. For the purpose of screening systems for flight testing, this availability must be at least 0.95. (A greater availability would be required for an eventually fielded system.)

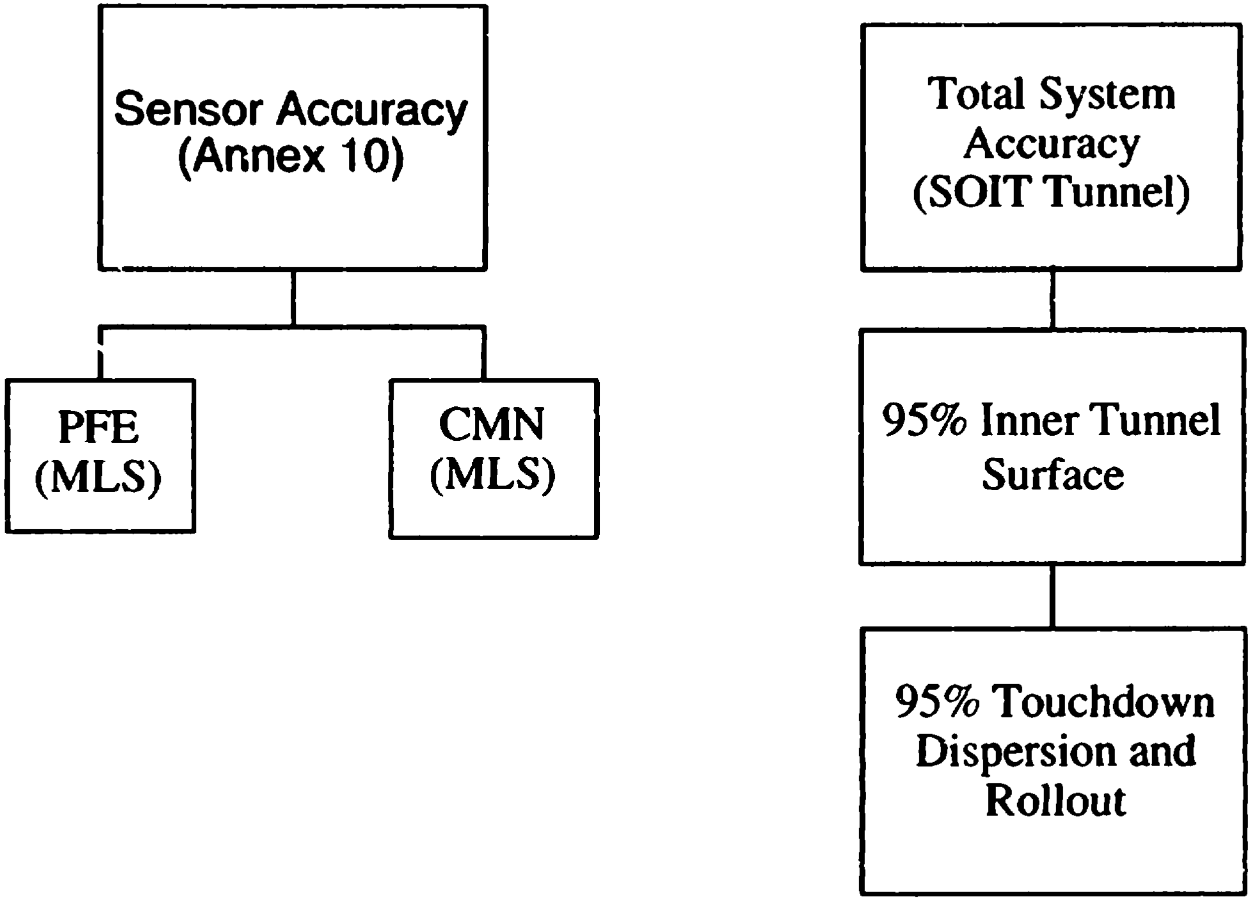

Figure 1. Flight-Test Accuracy Measures of Success (2 paths)

4. Either DGPS or DGPS/inertial may be used and integrated in any way by the contractor. These systems may be augmented by pressure altimeter, corrected barometric altimeter or radio altimeter (with no dependency on terrain mapping before threshold). The contractor will provide the FAA with diagrams of all sensor interconnections and a written description of how this guideline will be achieved.

5. For all approaches using flight director the subject pilot shall fly under hood.

6. The guidance point is the reference point on the aircraft to be flown along the desired approach path. The guidance point shall be selected by the contractor in such a way as to meet the accuracy and integrity requirements. The guidance point used and aircraft attitude determine the lever-arm correction required for the laser tracker truth position.

7. All differential data shall be reinitialized before each approach. Before each approach, at about 10 miles from the runway threshold and prior to activation of the DGPS, the position of any inertial reference system used shall be manually updated to a position 5 miles offset from present position.

8. The contractor is solely responsible for ensuring that the interfaces with any government furnished equipment provide the proper data flow for the contractor's equipment to meet its performance. To allow maximum flexibility in rearranging schedules, the Test Director and the government flight test organizations will ensure that any ICDs among the various organizations are as standard as possible.

9. The contractor is responsible for ensuring that its system is ready to demonstrate that it adequately meets the MOSs. Therefore, if during the flight trials it is indicated that the system is not meeting the MOSs, the contractor will be given a limited time to make any corrections. Thereafter, if it is again indicated that the system is not properly performing, the trials will be terminated. The testing will resume again only when it does not interfere with scheduled tests of other contractors' equipment. The retesting will be allowed only one time. These test decisions will be made by the Program Office (ARD-70) and the responsible government flight test organization.

10. Any change in equipment configuration during the conduct of a test must be approved by the ARD-70. This approval will be based on the degree of impact on the usefulness of data already collected for that equipment.

11. The contractor will be responsible for collecting the prescribed sensor data (Appendix B) for its equipment, and time stamping it as specified by the test organization. All of the final data collected by contractor and test facility shall be put into a standard format so that it can undergo independent analysis (the format will be specified in the Level 2 Test Plan).

12. The only outlier data that will be discarded from statistical analysis will be anomalies with known causes, such as laser tracker malfunction; the decision to exclude any collected data from the analysis will be made jointly by the FAA,

Stanford University and the test organization. However, any discarded data will be provided in reports with an explanation.

13. The public release of any test data or results is subject to approval by the FAA, Stanford University and the government flight test organization.

2.3 MEASURES OF SUCCESS (MOSs)

To ensure that test objectives are attained, MOSs have been formulated. An MOS is defined as a quantitative requirement, stated by the FAA, which must be satisfied by the results of these tests as one of the necessary conditions for validating whether a DGPS system demonstrates feasibility to meet CAT IIIb requirements (as specified in this plan) for accuracy and integrity. MOSs have been defined for each of the above objectives.

2.3.1 Accuracy Measures of Success

As shown above in Figure 1, accuracy performance will be determined by either: (1) sensor error, or (2) total system error, as described in more detail below.

2.3.1.1 Sensor Accuracy Measures of Success

Sensor error is determined by passing the difference between ground truth and the sensor output of the contractor's equipment through the ICAO Annex 10 [2] path following error (PFE) and control motion noise (CMN) filters for Microwave Landing System (MLS). The data that are used in the sensor evaluations must be equivalent to the data that are used to provide approach guidance in the contractor's equipment. The guidance update rate must be at least 5 Hz, and the data shall be provided to the FAA in the runway coordinates to be specified in the Level 2 Test Plan. For each flight to be considered successful, the filtered error output in a sliding window (refer to ICAO Annex 10) must be within the requirement 95% of the time. To determine whether the measures of success are met by the flight test, a statistical analysis procedure (described below) will be applied to the entire ensemble of 100 approaches.

MOS 1 Vertical sensor errors will be analyzed from 700 feet height above threshold (HAT) to 50 feet HAT. Vertical sensor error requirements are given in Table 2.

MOS 2 Lateral sensor errors will be analyzed from 200 feet HAT to 50 feet HAT and through completion of rollout. To expedite flight testing, 90 approaches shall be touch and go, and 10 shall involve rollout to a complete stop. Lateral sensor error requirements are given in Table 2.

Table 2. CAT III Sensor Accuracy Requirements (Based on MLS)

Vertical Error Requirements (95%)

HAT	PFE (m)	CMN(m)
700'	8.4	4.2
200'	2.4	1.2
100'	1.2	0.6
50'	1.2	0.6

Lateral Error Requirements (95%)

HAT	PFE (m)	CMN(m)
200'	5.1	4.1
100'	4.4	3.5
50'	4.0	3.2
Touchdown	4.0	3.2
Rollout	4.0	3.2

2.3.1.2 Total System Error Measures of Success

Total system error refers to the difference between the aircraft position and the position the aircraft should be at on the desired flight path. It is derived as the difference between the test range truth source and the desired point on the flight path. For each flight to be considered successful, all total system error measurements must be within the requirement. To determine whether the measures of success are met by the flight test, a statistical analysis procedure (described below) will be applied to the entire ensemble of 100 approaches.

MOS 3 Vertical total system errors will be analyzed from 700 feet HAT to 50 feet HAT. Figure 2 shows the tunnel-in-space [4] and Table 3 shows the vertical total system error requirements.

MOS 4 Lateral total system errors will be analyzed from 200 feet HAT to 50 feet HAT and through completion of rollout. Figure 2 shows the tunnel-in-space [4] and Table 3 shows the lateral total system error requirements.

MOS 5 The wheels of the aircraft must contact the ground within the touchdown dispersion area. The requirements are as specified in Table 3. Requirements were extracted from AC 20-57A [3]. To expedite flight testing, 90 approaches shall be touch and go, and 10 shall involve rollout to a complete stop. Wind conditions must be measured by the flight test organization and/or by the contractor in the aircraft during the flight tests. Dispersion requirements must be met for headwinds up to 25 knots, crosswinds up to 15 knots and tailwinds up to 10 knots.

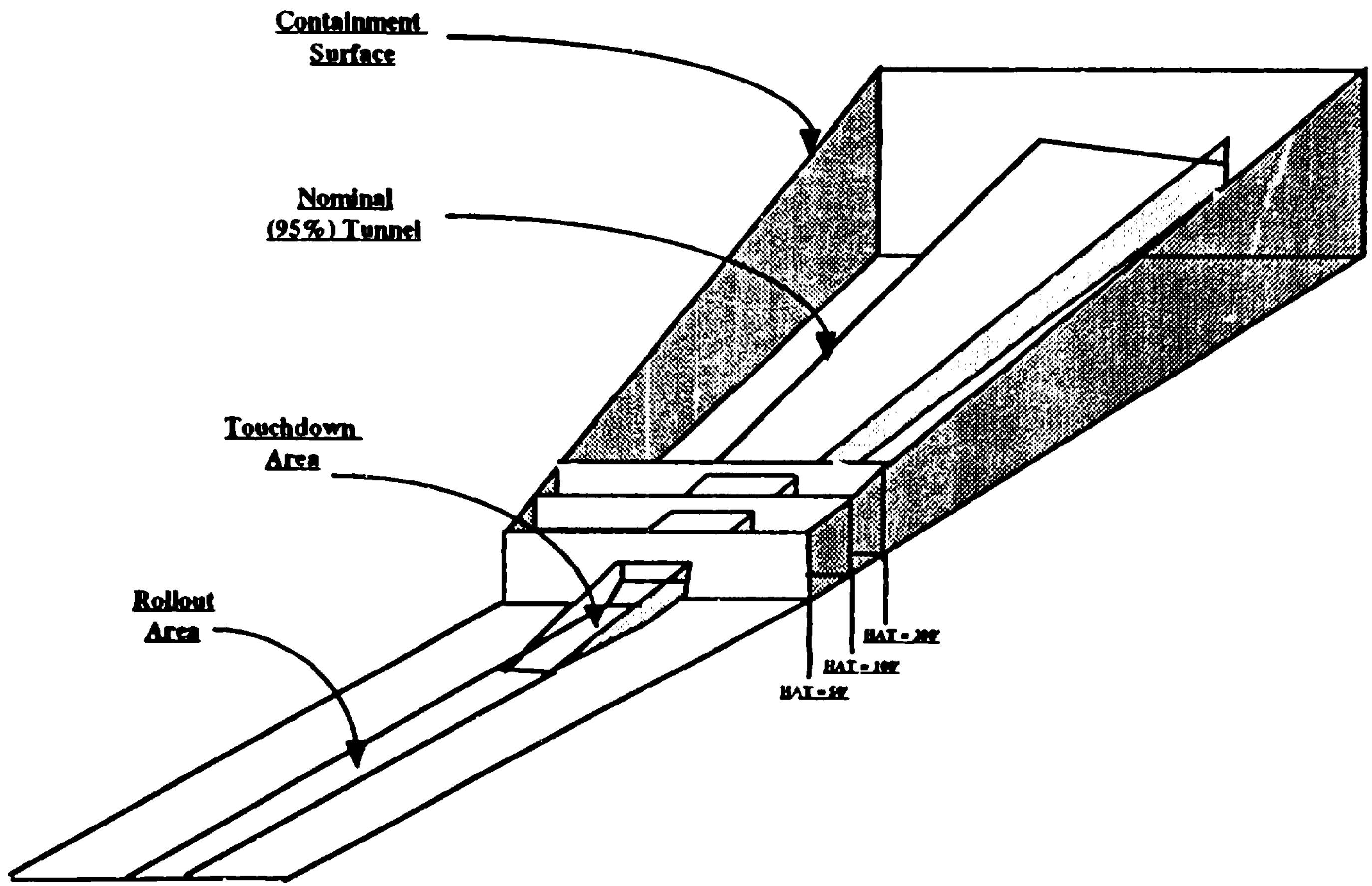

Figure 2. Vertical and Lateral Total System Error Requirements

Table 3. Total System Error Requirements

Inner Nominal (95th percentile) Surface

HAT	Vertical Error (half widths in ft/m)	Lateral Error (half widths in ft/m)
750'	89 / 27.1	275 / 83.8
200'	32 / 9.8	110 / 33.5
100'	15 / 4.6	75 / 22.9
50'	N/A	51 / 15.5

Touchdown Dispersion and Rollout Control Requirements

Lateral Touchdown Dispersion (95%)	±27 feet [1]
Longitudinal Touchdown Dispersion (95%)	1500 feet [2]
Lateral Rollout Control (95%)	±27 feet [3]

[1] Relative to runway centerline. See AC 20-57A [3].
[2] Relative to nominal point within the touchdown zone. See AC 20-57A [3].
[3] Distance from the aircraft centerline to the runway centerline. See AC 120-28C, Appendix 2 [1].

2.3.2 Integrity Measures of Success

Integrity measures of success will be based on either: (1) monitored DGPS data transmitted to the aircraft and subjected to alarm limits based on ICAO Annex 10 ILS tolerances [2], or (2) total system error where the alarm limits are derived from the outer tunnel-in-space [4] containment surface (refer to Figure 2). Table 4 defines the ILS near field monitor alarm limits applicable to (1) above and Table 5 defines the limits applicable to (2) above.

Table 4. Monitor Limits For Postion Errors Using Differential Data (Based on ILS)

Height above Threshold (ft)	Vertical (half widths in ft/m)	Lateral (half widths in ft/m)
100	7.5 / 2.3	21.9 / 6.7
50	7.5 / 2.3	20.0 / 6.1

Table 5. Integrity Limits for Total System Error

HAT	Vertical Error (half widths in ft/m)[1]	Lateral Error (half widths in ft/m)[1]
750'	242 / 73.8	784 / 239.0
200'	80 / 24.4	315 / 96.0
100'	35 / 10.7	215 / 65.5
50'	17.5 / 5.3	135 / 41.4
Touchdown	N/A	50 / 15.2
Rollout	N/A	50 / 15.2

[1] Outer tunnel [4] dimension minus approximate dimensions of B747.

For flight tests, a functional evaluation of system integrity will be performed in two ways.

MOS 6 Under normal operating circumstances (e.g., the equipment is tracking a set of satellites that meet its geometric constraints) there should be no false alarms for either (1) or (2) above. However, for the purpose of this evaluation, one false alarm shall be allowed among the 100 completed approaches that are analyzed. Moreover, if the monitoring tolerances are exceeded, an alarm must always be enunciated within 2 seconds.

MOS 7 To achieve a test of integrity logic, a second set of more stringent limits will be used to induce artificial alarms while the aircraft is stationary on the ramp. With artificial alarm limits, all violations shall be detected and the time-to-alarm should be ≤ 2 seconds. The contractor is responsible for defining the artificial alarm limits such that violations occur approximately once per minute. The artificial alarm limits used shall be defined as part of the contractor's design documentation. An integrity error occurs if the alarm does not trigger when the system error exceeds the defined threshold. No integrity errors should occur. The alarm response time will be determined by post-test analysis.

2.4 STATISTICAL APPROACH

The type of statistical hypothesis testing that is employed in quality control will be used to determine whether a particular accuracy MOS is achieved. Error observations will be made at the desired regions of interest along the approach path and compared to the a priori MOS limits. The number of successes (error within MOS limits) out of the total number of approaches will be compared to an acceptance threshold. If, for example, the level of significance (probability of rejecting acceptable system) is set at 5 percent, the acceptance threshold is 91 out of 100 completed approaches. Hypothesis testing will also be used to determine whether the touchdown displacements are within the two-sigma limits (assumed to be 95% limits) in AC 20-57A [3]. Estimation statistics, such as ensemble means and standard deviations, will also be computed.

The detailed statistical analyses, rationale for the number of trials, and truth source requirements (e.g., laser and TV (if used)) will be specified in the Level 2 Test Plan.

2.5 ORGANIZATIONAL RESPONSIBILITIES (PROVIDED BY PROGRAM OFFICE)

The following are the organizational responsibilities for the flight testing.

2.5.1 FAA Satellite Program Office (ARD-70)

- Provide overall program management and funding.
- Manage and control equipment demonstration contracts.
- Approve all test plans.
- Manage and coordinate award teams.

2.5.2 Stanford University

- Review test requirements and test plans for demonstrating feasibility.
- Serve as technical authority for source selection.
- Provide overall summary of performance, based on flight test reports.

2.5.3 Individual Flight Test Organizations (FAA Technical Center, NASA Ames Research Center)

- Based on Level 2 Test Plan, write Level 3 Test Plan for each contractor's equipment to be flight tested.
- As required, provide test equipment as specified in the Level 1 and Level 2 Test Plans, and coordinate necessary installations of equipment.
- Provide flight test schedules.
- Coordinate with contractors to ensure time synchronization of sensor and truth data collections.
- Coordinate radio frequency assignments for the contractor's equipment.
- Provide surveys for basic reference points, such as DGPS reference antenna, runway coordinates, and ramp check points. (Additional surveyed reference points shall be the responsibility of the contractor.)
- Provide straight-in CAT IIIb approach plate and waypoints for the flight test.
- Coordinate with contractors to ensure proper location of laser retroreflector on the aircraft, and check lever arm data.

- Provide laser tracking for ground truth, including calibration at proper intervals.

- Provide a means for measuring the wheel position at touchdown.

- Serve as on-site flight test director.

- Provide smoothed tracking data to all data analysis organizations and the contractor by the end of the day following each day of flight testing. For remote data analysis organizations, data should be sent by the flight test organization by express or electronic mail.

- Merge tracking data with flight test data immediately upon receipt of tracking and contractor data.

- Produce plots of error trajectories (as specified in the Level 2 Test Plan) within 24 hours of completion of a day's set of flight tests.

- Complete full data reduction and analysis of flight test data as specified in the Level 2 Test Plan within 30 days of completion of a contractor's flight test.

- Prepare reports of flight test results following the outline contained in the Level 2 Test Plan.

2.5.4 Satellite Operational Implementation Team (SOIT)

- Review and approve Level 1 and Level 2 Test Plans. This includes providing values of required performance needed in the test plan. Review Level 3 Test Plans as needed.

- Provide guidance for data collection and analysis with respect to demonstrating compliance with MOSs.

2.5.5 Contractor

- Provide a fully equipped aircraft capable of satisfying the MOSs contained in this document.

- Ensure interfaces provide the proper data flow for the equipment to meet its required performance.

- Provide information to the FAA on satellite geometry constraints.

- Provide information to the FAA on readiness of equipment to meet flight MOSs.

- Provide recorded data (see Appendix B) to the test organization in designated format at the end of each day of flight testing.

- Provide a weight-on-wheels indicator to allow marking touchdown point in recorded data.

- Support data reduction and analysis, including explanations of unexpected results, such as significant biases and excessive noise.

- Support the preparation of reports.

- If required by the contractor's design, the contractor shall provide the survey of sites in addition to those surveyed sites provided by the test organizations.

- Provide lever-arm data (retroreflector to GPS guidance point) to flight test organization.

- Provide the FAA and Stanford University with block diagrams that explicitly show sources and interconnections from which all sensor and integrity data are generated, and how the sensor and integrity data interfaces with the flight guidance system.

- Adhere to other responsibilities as described in Appendix A.

2.5.6 MITRE's CAA3D

- Serve as general flight test director, providing the necessary guidance and coordination for accomplishing the flight testing.

- Prepare and coordinate the Level 1 Test Plan and Level 2 Flight Test Plan.

- Provide an independent merge, reduction, and analysis of all data, and coordinate comparison of results with test organizations.

- Support the FAA in preparation of reports.

SECTION 3

SATELLITE SIMULATOR TEST (SST)

3.1 TEST OBJECTIVES

Based on the results of flight testing, contractor systems may be subjected to an optional satellite simulator test. The overall objective of the optional SST is to characterize the robustness, integrity function, and accuracy of contractors' equipment through programmed variations in the simulated GPS satellite signals, environment, and tracked satellites. The NRaD Central Engineering Activity (CEA) simulation laboratory, Warminster, PA, will be used for these tests. The contractor's ground reference station, aircraft receiver, and monitor station will be utilized in the simulation as a complete system. They shall be configured in the same manner as in the flight tests with respect to reference station update data content and rate, and location of reference and ground-monitor stations. GPS/DGPS enhancements such as altimeter and IRS, will be simulated via real-time software models.

3.2 PERFORMANCE CHARACTERISTICS TO BE MEASURED

For each test vary the satellite geometry in accordance with diurnal cycle (within the stated constraints e.g., DOPs, mask angle, minimum number of satellites of a contractor's equipment as used during flight test) to determine the performance characteristics. The Level 2 Test Plan will define for each test where in the approach the variations will occur, the frequency of the variations, and the magnitude of the variations.

3.2.1 Specific Tests

Determine response of a contractor's equipment to the following conditions.

1) Multipath disturbances. Multipath disturbances to satellite signals at ground reference stations and aircraft that may cause large position errors will be simulated. The goal is being able to coast through a large signal error caused by multipath, where the sensor accuracy during the coast is within SST-alarm limits (see 3.2.2). The test characteristic is the percent of these trials that are successfully completed within the SST alarm limits. Also, upon declaration of exit from coast, the sensor accuracy is within SST-alarm limits; or if out of limits an alarm is enunciated.

2) Signal drop out. The impact of this disturbance will be evaluated primarily for the aircraft receiver. The goal is being able to coast through a drop-out of all satellite signals. The remainder of the test is the same as for multipath.

3) Loss of integer ambiguity resolution (for kinematic GPS). Determine the reinitialization time (after loss of integer ambiguity resolution, the time required to reinitialize and resolve the ambiguity search). The impact of this disturbance will be evaluated for the aircraft receiver. The characteristic is the distribution of reinitialization times.

4) Subtle satellite signal failures (e.g., ramp errors). The ramp error rates will be large enough to drive the sensor errors beyond the SST-alarm limits (see 3.2.2). The goal will be that the integrity monitoring system detects out of tolerance sensor errors within its set alarm limits and time to alarm.

5) Switching to a new satellite during approach. The goal is that the performance is maintained within the SST-defined alarm limits (see 3.2.2) for any perturbation of the navigation position solution due to switching to a new satellite.

6) Variation in satellite signal power levels. The impact of this variation will be evaluated for the entire system. All satellite signal levels will be set at the minimum value specified for GPS. The goal is that the system performs within its accuracy tolerances.

3.2.2 Simulation Concept

quipment responses to the above signal variations, the performance will be based on the response of the guidance and integrity functions. This is illustrated in Figure 3 where the response is either "valid" guidance signals or an alarm indicating the sensor or position error tolerance has been exceeded. This response will be compared to the true state which is known to the simulation system. For CAT III, the lateral and vertical time to alarm is 2 seconds (ILS).

The same integrity scheme as used in the flight tests shall be employed. If the scheme involves knowledge of flight technical error (FTE), then the root mean square (RMS) FTE from the flight tests shall be used.

3.3 ORGANIZATIONAL RESPONSIBILITIES (PROVIDED BY PROGRAM OFFICE)

The following are the organizational responsibilities for the SST.

3.3.1 FAA Satellite Program Office (ARD-70)

- Provide overall program management and funding
- Approve all test plans

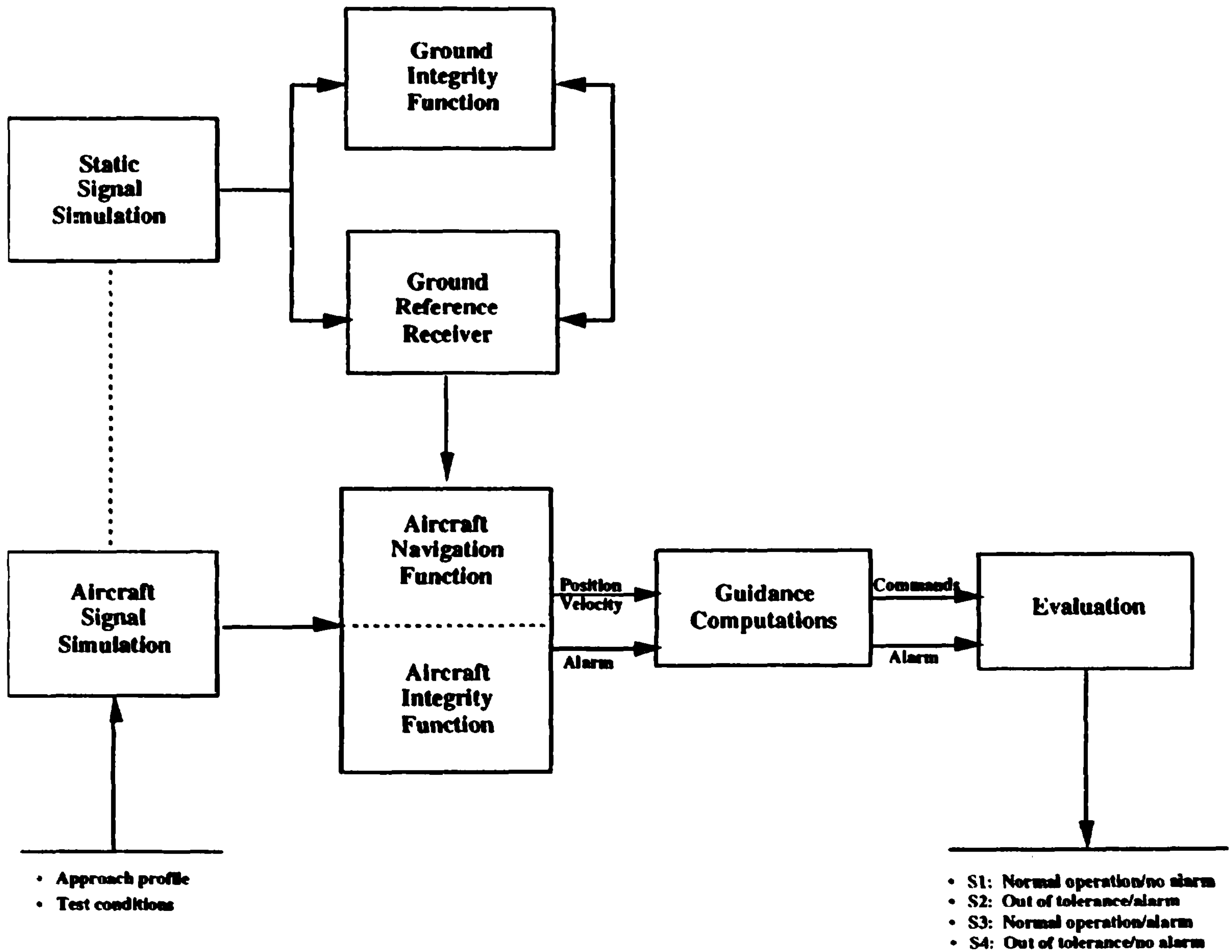

Figure 3. CAT III Satellite Signal Simulation Concept

3.3.2 Stanford University

- Review test requirements and test plans for examining equipment performance characteristics.
- Provide overall summary of performance, including satellite simulator test reports.

3.3.3 NRaD

- Based on this document, produce the Level 2 Test Plan, including the appropriate ICDs and other general requirements that a contractor's equipment must meet to be exercised in the CEA laboratory, the data to be collected, sample sizes, how the data will be reduced and analyzed to characterize performance, and an outline for the test report on a contractor's equipment.
- Based on the FAA approved Level 2 Test Plan, produce individual Level 3 Test Plans for each contractor's equipment.
- Reduce and analyze SST data as specified in Level 2 Test Plan.
- Generate individual reports of satellite simulator test results following the outline contained in the Level 2 Test Plan.

3.3.4 SOIT

- Review Level 1 and Level 2 Test Plans. Review Level 3 Test Plans as needed.
- Provide guidance for simulation data collection and analysis with respect to characterizing performance.

3.3.5 Contractor

- Provide all agreed upon avionics (including guidance command output), monitor and ground-reference equipment to NRaD, including specified parameters of inertial reference unit and altimeter if integrated into system.
- Design equipment according to the ICDs for interface with government equipment.
- Inform NRaD about geometry constraints and readiness of equipment for testing.
- Provide NRaD with block diagrams that explicitly show sources and interconnections from which all sensor and integrity data are generated and how the sensor data interfaces with the flight guidance system.
- Support data reduction and analysis, including explanations of unexpected results, such as significant biases and excessive noise.
- Support the preparation of reports.

3.3.6 MITRE's CAASD

- Produce and coordinate the Level 1 Simulation Test Plan (Section 3 of this document).
- Provide guidance for the accomplishment of the simulation testing.

SECTION 4

FLIGHT READINESS REVIEW

4.1 REVIEW OBJECTIVE

Prior to flight tests, perform a flight readiness review to estimate whether a contractor's equipment performance (including operation of integrity function) is ready for those tests. The test will involve observing system performance in the contractor's aircraft and evaluating data recorded onboard the aircraft and by the laser tracker.

4.2 REVIEW GUIDELINES

1. The flight readiness review will be conducted at one of the two government flight test facilities. The contractor must provide the aircraft and all test equipment.

2. The flight test course will be a straight-in precision approach.

3. The contractor will record data as specified in Appendix B. In addition, the contractor will display the aircraft's 3-dimensional sensor indicated position. The data will be viewed by the FAA in real-time and copies of the recorded data will be provided for additional review.

4. The retroreflector will be installed on the aircraft, and operation of ground truth system verified including merge with contractor recorded data.

5. On each approach trial a contractor's DGPS equipment shall be used for aircraft guidance in the same manner as proposed for the flight tests. To do an efficient preliminary assessment of system performance, total system error will be evaluated based on aircraft position as measured by the laser tracker. Information such as trial number, average horizontal dilution of precision (HDOP) and vertical dilution of precision (VDOP) during the trial, and comments on observations of the DGPS guidance performance made in the aircraft will be recorded on log sheets for each trial.

6. The flight readiness review will be performed during intervals which satisfy satellite geometry constraints required by the contractor's system.

7. The system configuration (hardware and software) during the review shall be identical to the configuration that will be flight tested. This includes any additional sensors used in the DGPS solution.

8. An FAA program office representative, the test director, and testing organization representative (from the FAA Technical Center or NASA Ames) will be present to observe the flight readiness review.

4.3 MEASURES OF SUCCESS

To ensure that the test objective is attained the following measures of success have been formulated.

1. An approach trial will be considered successful if the total system error as determined by the laser tracker is always within the 95% inner tunnel [4] requirements (Table 3) from 700 feet HAT through 200 feet HAT. At least 5 successful approaches in a row shall be accomplished within a two day period.

2. The DGPS system must provide continuity of navigation throughout the final approach course. The continuity of navigation for the flight readiness review will be determined by observing and recording any loss of guidance information.

4.4 ORGANIZATIONAL RESPONSIBILITIES (PROVIDED BY THE PROGRAM OFFICE)

The following are the organizational responsibilities for the flight readiness review.

4.4.1 FAA Satellite Program Office (ARD-70)

- Provide overall program management and funding.
- Approve all test plans.
- Manage and control equipment demonstration contracts.

4.4.2 Stanford University

- Participate in evaluating flight readiness.

4.4.3 Individual Flight Test Organization

- Provide information needed by contractor such as approach plates, waypoints, surveyed locations of reference points and coordination of radio frequency assignments.
- Provide retroflector and ground truth system.
- Provide observers to participate in qualitative evaluation of contractor's system.
- Examine data recorded by contractor to verify format and content is as requested.

4.4.4 SOIT

- Provide advice for use in evaluating flight readiness.

4.4.5 Contractor

- Provide all agreed upon avionics and ground-reference equipment.
- Provide flight safety plan coordinated with flight test facility.
- Provide sample of recorded data for examination by the testing organization.
- Support the preparation of test memoranda.
- Adhere to other responsibilities as described in Appendix A.

4.4.6 MITRE's CAASD

- Serve as general flight readiness review director, providing the necessary guidance and coordination for accomplishing the review.
- Support the FAA in preparation of test memoranda.

LIST OF REFERENCES

1. *Criteria for Approval of Category III Landing Weather Minima*, Department of Transportation, Federal Aviation Adminstration, AC 120-28C, 3 September 1984.

2. *International Standards, Recommended Practices and Procedures for Air Navigation Services, Aeronautical Telecommunicutions*, Annex 10 to the Convention on International Civil Aviation, Volume 1, International Civil Aviation Organization, April, 1985.

3. *Automatic Landing Systems*, Department of Transportation, Federal Aviation Administration, AC 20-57A, 12 January 1971.

4. Davis, J. & Kelly, R., *RNP Tunnel Concept for Precision Approach with GNSS Application*, Proceedings of the Institute of Navigation Annual Meeting, 21-23 June 1993.

APPENDIX A

SUMMARY OF ESTIMATED CONTRACTOR RESPONSIBILITIES FOR DETERMINING LEVEL OF EFFORT FOR TEST PHASES

The purpose of this appendix is to summarize a contractor's expected responsibilities during the test phases. A contractor can then use this information to estimate its required resources to participate in the tests.

A.1 ESTIMATED CONTRACTOR RESPONSIBILITIES FOR FLIGHT READINESS REVIEW

1. It shall be assumed that a contractor's system is in working order prior to the flight readiness review at one of the two government flight test facilities. Therefore, a contractor shall install and fly the complete system at an airport, including all of the data recording equipment, to make sure its system is in working order prior to the review. A contractor shall also have installed the fittings for the laser tracker retroreflector, and have completed coordination of the Level 3 Test Plan and flight safety plan with the designated flight test facility test manager.

2. A contractor shall plan to spend a maximum of two days at one of the two flight test facilities. A contractor shall set up, adjust and maintain the ground equipment during this time, and install the laser tracker retroreflector.

3. During these two days, a contractor is required to complete at least 5 successful approaches in a row, and shall provide sufficient personnel in the aircraft and on the ground to ensure that the Category IIIb (CAT IIIb) system is performing properly, and to provide answers to all questions concerning the equipment and its performance that may be asked by the personnel designated by the FAA to monitor the flight readiness review. Required recorded data for at least 5 flights shall be provided to the flight test facility in the format specified by the Level 2 Test Plan.

4. If a CAT IIIb system does not complete the required 5 successful approaches during the two day period allocated for the flight readiness review and a contractor decides to try again at another time, then the government shall not reimburse the contractor for any expenses incurred for the second flight readiness review.

5. Space for at least one FAA-designated observer shall be provided on a contractor's aircraft.

A.2 ESTIMATED CONTRACTOR RESPONSIBILITIES FOR FLIGHT TESTS

1. By noon of the first day of scheduled flight tests, a contractor's CAT IIIb prototype, including data collection equipment, shall be completely ready for flight testing.

2. Two weeks shall be allotted for the completion of at least 90 touch-and-go approaches and 10 roll out approaches. In the event of a malfunction that can not be corrected immediately, a contractor shall have its equipment ready to resume flight testing as soon as possible. If there is another such equipment malfunction, a contractor's CAT IIIb prototype shall be rescheduled for another two week period with the same conditions of allowable malfunctions. The rescheduled period shall not interfere with the scheduled testing of other contractors' systems. No more than two, two week periods shall be allocated for a contractor's flight tests.

3. A contractor shall provide sufficient personnel in the aircraft and on the ground to ensure that the CAT IIIb prototype is performing properly, equipment is properly adjusted and maintained and all required recorded data is provided to the designated flight test facility manager, and someone is available to answer all questions concerning the equipment and its performance that may be asked by the personnel designated by the FAA to monitor the flight tests. Required recorded data for each day's flights shall be provided to the designated flight test facility manager at the end of each day of testing. This data shall be provided in the format specified by the Level 2 Test Plan.

4. A contractor shall provide a subject pilot and a safety pilot. For all approaches using flight director the subject pilot shall fly under hood.

5. Due to adverse weather, airfield usage priorities and other contingencies, some of the flights may have to be flown at night and during early morning. A contractor shall provide the proper level of personnel to cover these periods of "off hours testing."

6. Before and after each day's flights, a contractor shall lead a meeting to discuss the events of the day, and to plan subsequent flight tests.

A.3 ESTIMATED CONTRACTOR RESPONSIBILITIES FOR SATELLITE SIMULATION TESTS

1. The laboratory simulation tests will be performed by the Government at the Naval Command Control and Ocean Surveillance Center (NCCOSC) Research Development Test and Engineering Division (NRaD) Detachment Warminster PA GPS Central Engineering Activity (CEA). The evaluation will consist of both performance and characterization tests in accordance with the Level III Laboratory Test Plan. The contractor shall deliver its precision approach system and any special test equipment to NRaD within two weeks after receipt of notification of exercise of the simulation test option.

2. In preparation for these tests, when notified by the Government, the contractor shall participate in a system functional checkout of the Laboratory installation and provide the Government with a written and oral, hands-on familiarization briefing of their system configuration (at the Laboratory). This includes theory of operation, special test equipment, and system operating and diagnostic procedures. At this time, the contractor shall define, in writing, any changes in system configuration implemented after the flight tests. The notification shall include reason for the change, description of the change, and expected impact of system performance.

3. The Laboratory test period is expected to last approximately one month commencing immediately after completion of the familiarization briefing. During the test period, the contractor shall provide maintenance support and technical guidance as required on a standby basis for the duration of the Laboratory tests. The contractor is responsible for providing all necessary maintenance and diagnostic equipment to support the precision approach system operation. The contractor shall provide a brief written description of any maintenance actions performed on the system during the test period including the reason for the action and expected impact on system performance, prior to resumption of the laboratory tests.

APPENDIX B

IDENTIFICATION OF FLIGHT TEST DATA TO BE RECORDED

This appendix contains tables that identity the required data to be recorded during the flight tests, including resolution and units. The exact format for presenting the recorded data to the FAA shall be specified in the Level 2 Test Plan.

The following general guidelines for the recording of data shall be followed.

1. All data shall be recorded as ASCII characters. in MOS-DOS compatible files.

2. The intervals between recorded data and time tags shall be within 0.001s.

B.1 AIRCRAFT RECORDED DATA: BASIC DATA SET

The basic data set covers the data required for determining whether the MOSs are met, and for helping in the explanation of performance. It is presented in Table B-1. To facilitate the merging of basic truth data, all data shall be recorded at a rate of 10 Hz.

B.2 AIRCRAFT RECORDED DATA: SUPPLEMENTAL SET

The supplemental set covers data that is recorded at a slower rate. It is presented in Table B-2, and it shall be recorded at a rate of at least 1 Hz.

B.3 GROUND DGPS REFERENCE STATION RECORDED DATA

The reference station data shall be used to verify the integrity of the DGPS data. It shall be recorded at the same rate as the DGPS data, as outlined in Table B-3. Since the salient data of a contractor's integrity function is not known at this time, the exact data to be recorded shall be coordinated by the FAA and a contractor, and specified in the Level 3 Test Plan.

B.4 GROUND DGPS MONITOR STATION RECORDED DATA

The monitor station data shall be used to verify the integrity of the DGPS data. Its outline is presented in Table B-4, and it shall be recorded at the same rate as the DGPS data. The data to be recorded shall contain the output of the integrity processing and its decisions. Since the salient data of a contractor's DGPS scheme and its integrity scheme are not known at this time, the exact data to be recorded shall be coordinated by the FAA and a contractor, and specified in the Level 3 Test Plan.

B.5 DESIRED FLIGHT PATH DATA

The desired flight path data shall be used in the determination of total system error. Its outline is given in Table B-5.

Table B-1. Basic Data Recorded on Aircraft

Basic Data	Resolution	Units
Time		
GPS	10^{-3}	s
DGPS Sensor		
East (RWY)*	10^{-2}	ft
North (RWY)	10^{-2}	ft
Up (RWY)	10^{-2}	ft
Ground Speed	10^{-1}	ft/s
DGPS/IRS Sensor		
East (RWY)	10^{-2}	ft
North (RWY)	10^{-2}	ft
Up (RWY)	10^{-2}	ft
Ground Speed	10^{-1}	ft/s
Guidance Deviation		
Vertical (-FTE)	10^{-1}	ft
Lateral (-FTE)	10^{-1}	ft
Integrity		
Vertical Alarm	0/1	off/on
Lateral Alarm	0/1	off/on
Airspeed	10^{0}	kn
Attitude (IRU if available)		
Roll	10^{-1}	deg
Pitch	10^{-1}	deg
Heading (True)	10^{-1}	deg
Wind (if available)		
Speed	10^{0}	kn
Direction	10^{0}	deg
Altimeter Sensor		
Radar	10^{-1}	ft
Barometric	10^{-1}	ft
Weight-on-Wheels (activated at touchdown)	off/on	

* RWY = Runway Coordinates

Table B-2. Supplemental Data Recorded on Aircraft

Supplemental Data	Resolution	Units
Time		
GPS	10^{-3}	s
IRS		
East (ECEF)	10^{-2}	ft
North (ECEF)	10^{-2}	ft
Up (ECEF)	10^{-2}	ft
Ground Speed	10^{-1}	ft/s
ILS		
Glide Slope Dev.	10^{-3}	deg
Localizer Dev.	10^{-2}	deg
Satellites		
VDOP	10^{-1}	
HDOP	10^{-1}	
No. Of Satellites Used in Navigation Solution	10^{0}	
Identity of Satellites Used	10^{0}	SV No.
Elevation Angle of Satellites Used	10^{-1}	deg

Table B-3. Data Recorded at DGPS Reference Station

Reference Sta. Data	Resolution	Units
Time		
GPS	10^{-3}	s
DGPS Data		
	TBD	**TBD**
Integrity Data		
	TBD	**TBD**

Table B-4. Data Recorded at DGPS Monitor Station

Monitor Sta. Data	Resolution	Units
Time		
GPS	10^{-3}	s
Integrity Data	**TBD**	**TBD**

Table B-5. Desired Flight Path

Desired Flt. Path Data	Resolution	Units
East (Reference to RWY)	10^{-2}	ft
North (Reference to RWY)	10^{-2}	ft
Up (Reference to RWY)	10^{-2}	ft

GLOSSARY OF ACRONYMS

AC	Advisory Circular
ARD-70	FAA's Satellite Program Office
ASE-300	FAA's National Airspace System Engineering Service
CAASD	MITRE's Center for Advanced Aviation System Development
CAT	category
CEA	Central Engineering Activity (of NRaD)
CMN	control motion noise
DGPS	differential GPS
DH	decision height
DOP	dilution of precision
ECEF	earth -centered, earth-fixed (coordinate system)
FAA	Federal Aviation Administration
FTE	flight technical error
GPS	Global Positioning System
HAT	height above threshold
HDOP	horizontal dilution of precision
ICAO	International Civil Aviation Organization
ICD	interface control document
ILS	Instrument Landing System
IRS	inertial reference system
MLS	Microwave Landing System
MOS	measure of success
NCCOSC	Naval Command Control and Ocean Surveillance Center
NASA	National Aeronautics and Space Administration
NRaD	Research Development Test and Engineering Division Detachment
PFE	path following error
RFP	Request For Proposals
RMS	root mean square
RWY	runway (coordinate system)
RVR	runway visual range
SOIT	Satellite Operational Implementation Team
SST	satellite simulator test
VDOP	vertical dilution of precision